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ONTARIO Ministry of the Environment

THE MOIRA RIVER STUDY
SUMMARY REPORT
January, 2001

Conducted and Prepared for
The Ministry of the Environment

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GLOBALTOX

INTRODUCTION

The *Moira River Study* is one part of the ongoing Deloro Mine Site cleanup – a project of the Ontario Ministry of the Environment, which also includes the Deloro Village Environmental Health Risk Study and the development and implementation of a final cleanup program for the Deloro Mine Site.

One hundred years of mining and refining at the Deloro Mine Site contributed significant amounts of metals to the Moira River system including arsenic, nickel and cobalt. The Moira River flows through the Deloro Mine Site and thereafter to Moira and Stoco lakes before discharging into Lake Ontario at the Bay of Quinte at Belleville.

The *Moira River Study* was commissioned by the Ministry of the Environment (MOE) in 1999 to determine the extent of effects from the Deloro Mine Site on the Moira River and to predict the environmental response to the final cleanup of the site. The MOE established a Steering Committee to direct and oversee this Study. This committee included technical staff from the MOE and representation from the Ministry of Natural Resources, Quinte Conservation Association and the Hastings and Prince Edward Counties Health Unit. Phase I of the *Moira River Study,* carried out by Water Systems Analysts (W B. Kilgour), C. Portt and Associates and Dr. D.G. Dixon (University of Waterloo), was completed in February 1999. Phase I involved the review of existing studies of the Moira River watershed. Information gaps were identified and a detailed study design developed for Phase II: a comprehensive assessment of the aquatic environmental effects on the Moira River below the Deloro Mine Site downstream to Belleville. The Steering Committee and the Moira Lake Property Owners' Association provided input to this study design.

Golder Associates Ltd, in partnership with GlobalTox International Consultants Inc., was retained in April 1999 to carry out the second phase of the *Moira River Study*. This second phase addressed effects on water, sediment, bottom dwelling (benthic) invertebrates and fish in the Moira River system. It also included a Preliminary Quantitative Risk Assessment, to determine if there are any potential health implications for people living downstream of the Deloro Mine Site. Computer modelling was conducted to examine the long-term effects on water and sediment quality that would result from the reduction or elimination of metals from the Deloro Mine Site as part of the final cleanup plan.

The *Moira River Study* Steering Committee reviewed the draft Phase II report of this study. The draft was also "peer reviewed" by a panel of international experts in the fields of biology, chemistry, toxicology, radioactivity, environmental modelling and risk assessment. The report was finalized to address comments from the Steering Committee, the peer reviewers and comments received from the public during the public consultation period that ended on September 26, 2000.

BACKGROUND

The Deloro Mine Site - History

The Deloro Mine Site is located where the Canadian Shield meets the Great Lake lowlands, about 45 kilometres north of Belleville, Ontario (Figure 1). Gold mining started here in the late 1860s. By the early 1900s, the gold mines had closed and the site was used to process silver and cobalt ores imported from other mines in northern Ontario. From the 1930s to the 1950s, smelted ore was brought from Eldorado Nuclear Limited in Port Hope for further refinement to extract the cobalt. Deloro was the first plant in the world to produce cobalt commercially and was also a leading producer of stellite, a cobalt-chromium-tungsten alloy highly valued during the war years. Ores from all over the world were processed in Deloro's smelters. Pesticides were produced from the arsenic by-products of the smelting operations and manufactured as a major activity at the site until those products were replaced by organic pesticides in the late 1950s.

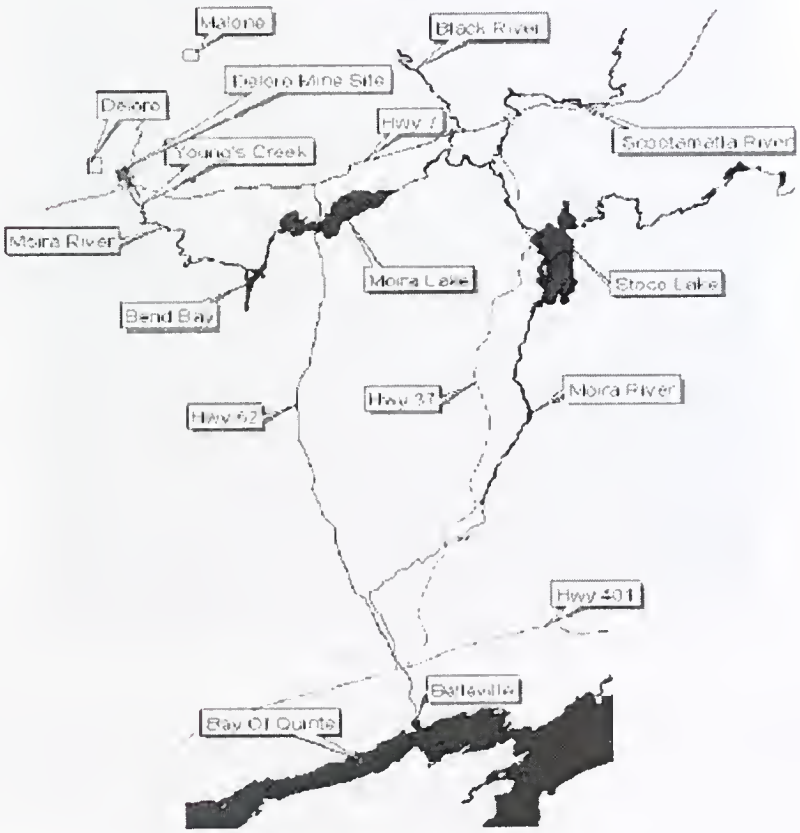

Figure 1 - The Moira River Watershed

BACKGROUND

Ministry of the Environment Involvement

By the time all operations ceased, a wide variety of discarded waste materials containing arsenic and a variety of other metals had affected the quality of water and soils on the site, as well as the quality of water and sediment in the Moira River system. When the last owners abandoned the property in 1979, the Ministry of the Environment assumed responsibility for the environmental management of the site as 'remediator of last resort'.

Since then, the ministry has made significant reductions in the contamination through a number of remedial actions. Eight hectares of tailings were covered, unsafe buildings demolished and mine shafts were located and sealed. The ministry also built and continues to pay for the operation of a treatment plant that removes arsenic and other heavy metals from the groundwater on site. As a result of these actions, the ministry has reported that loadings of arsenic to the Moira River have been reduced by more than 80 per cent. Recent investigation work has shown the presence of radioactive materials in Young's Creek, north of Highway #7, due to minor historic releases; however, the radioactivity observed has been restricted to that portion of the creek, which is within the boundaries of the mine site. The ministry's consultants are currently working on a plan for the final cleanup of the mine site, to control and securely contain all types of contamination at the site - from arsenic to radioactivity. The proposed interim Provincial Water Quality Objective (PWQO) for arsenic of 5 micrograms per litre will be one of the cleanup objectives. The ministry proposes to meet this interim PWQO on average, at the Highway 7 site boundary. This is significantly more stringent than the current PWQO of 100 micrograms per litre for arsenic.

The ministry also conducted a comprehensive Environmental Health Risk Study in the Village of Deloro. This study, released in July 1999, showed that it is safe to live in the Village of Deloro.

The Moira River System

The Moira River rises on Precambrian rocks of the Canadian Shield to the north of the Deloro Mine Site. Here the river is relatively unproductive; fish and benthic invertebrate populations are small and form communities of relatively low species diversity. In the vicinity of the Deloro Mine Site, the Moira River flows over rocky substrates with relatively limited areas for sediment deposition of fine materials like silt and organics (Figure 2). More abundant and diverse fish and benthic invertebrate communities are observed in this section of the river.

BACKGROUND

Young's Creek is a small tributary that begins in the vicinity of the mine site and empties into the Moira River below Highway 7. This creek contains an extensive accumulation of sediment in ponded areas (Figure 3) contained by a series of beaver dams.

Downstream from the mine site, the river flows relatively rapidly over rock until it approaches Bend Bay. From this point downstream, the river is characterized by sluggish flow with areas of extensive sediment deposition. Both Moira and Stoco Lakes lie in this section of the river. Significant quantities of sediments have accumulated in the deep basins of these lakes. This section of the watershed, including Moira and Stoco Lakes, supports highly productive plankton and aquatic plant-based food webs that sustain diverse fish communities.

Figure 2 - View of Moira River at the Deloro Mine Site

The mean annual flow of the Moira River at Highway 7 is 3.8 m^3/sec. Flow is strongly seasonal, ranging from a mean monthly high flow of 14.3 m^3/sec in April to a mean monthly low of 0.3 m^3/sec in August.

BACKGROUND

Figure 3 - View of Young's Creek Above Confluence with Moira River

Cottages, campgrounds and parks encircle each of Moira and Stoco Lakes and provide access to swimming, fishing, boating and watersports in the summer, and ice fishing, cross-country skiing and snowmobiling in the winter for local residents and visitors (Figure 4). It is estimated that there are about 624 residences between Deloro and the outlet of Stoco Lake, of which about half are cottages. The majority of these are located in the vicinity of the lakes. There are a few residences in the area between Moira Lake and the Deloro Mine Site. Recreational use of this section of the river is limited because of the generally rocky nature of the substrate.

Figure 4 - Cottages on Moira Lake

STUDY OVERVIEW AND FINDINGS

Study Objectives

The Moira River system has historically been affected by metals in both water and sediment originating from the Deloro Mine Site – because of 100 years of mining and refining operations. The purpose of the *Moira River Study* is threefold:

1) To determine the concentration of metals present in the river system and to what degree the aquatic environment is being affected;

2) To determine if and how these metals of concern pose any potential health implications to people living downstream of the Deloro Mine Site; and

3) To predict how the aquatic environment will improve in response to final cleanup work at the Deloro Mine Site.

AQUATIC EFFECTS STUDY

This part of the *Study* addressed objective #1 by examining metal concentrations in water and sediment and assessing to what degree the aquatic environment is potentially being affected. Water quality, sediment quality, benthic invertebrates and fish were assessed throughout the Moira River system, from just below the Deloro Mine Site to as far downstream as Belleville.

Objective #1:

Determine the concentrations of metals present in the river system and to what degree the aquatic environment is being affected.

Metals of Concern

The Aquatic Effects Study focused on a short-list of 'metals of concern' consisting of arsenic, nickel, cobalt, copper, lead, and silver. These 'metals of concern' were also considered in the following parts of this study, the preliminary quantitative risk assessment and the predictive modelling.

This short-list was developed by screening the comprehensive 35-year record of monthly water quality data developed as part of the Provincial Water Quality Monitoring Network by the MOE's Environmental Monitoring and Reporting Branch. The results of additional water quality samples collected at onsite locations by the Ontario Clean Water Agency (OCWA), the operators of the treatment plant at the Deloro Mine Site, were included in this database. This database included the routine analysis of several metals, plus other parameters such as dissolved oxygen and turbidity and was augmented in 1999 and 2000 with the results of analysis of water samples for radioactivity.

Provincial Water Quality Objectives (PWQOs)

A set of maximum acceptable concentrations of substances in water. These guidelines were developed for the protection of aquatic life and recreation in and on the water. These are not the same as the objectives for the protection of drinking water supplies.

The data were examined for metals with concentrations that were consistently higher than Provincial Water Quality Objectives (PWQOs), Provincial Sediment Quality Guidelines, or higher than those observed at reference sites.

The metals with elevated concentrations in water and sediments were arsenic, nickel, cobalt, copper and lead. Silver was included in the short list because,

although it was not measured very often, it is one of the more toxic metals to aquatic organisms. Uranium was included for sediments only because uranium concentrations in sediments were elevated at sites in and near Young's Creek. Other radionuclides were not included in the short list because concentrations were not elevated in water or sediments.

Sampling Program

Water quality sampling has been conducted in the Moira River watershed since 1965, generally on a routine basis. Water quality samples have been collected at the Deloro Mine Site on a weekly basis since 1993 by OCWA, while the Quinte Conservation Association, on behalf of the ministry, conducts monthly sampling elsewhere in the watershed. The only water sampling conducted specifically for this study was the collection of samples for the analysis of radioactivity.

Figure 5 - Collecting Sediment Samples at Stoco

The ministry's 35-year record of monthly water quality data provided a clear indication of water quality trends in the Moira River system over time. This database was used as the basis for assessing water quality in the Moira River watershed. Other than sampling for the analysis of radioactivity as noted above, no water quality sampling was conducted specifically for this *Study*.

STUDY OVERVIEW AND FINDINGS

An extensive field program was conducted by field crews from the Ministry of the Environment and Golder Associates to collect the samples of sediment, benthic invertebrates and fish for this *Study*. The ministry conducted all sediment and benthic invertebrate sampling (Figure 5), while Golder Associates was responsible for the sampling of selected fish species. The Sport Fish Contaminant Monitoring Program continues to be conducted by the Monitoring and Reporting Branch of the MOE.

Sample Site Selection

Locations for the collection of sediment, benthic invertebrates and fish were selected to be representative of river and lake conditions downstream of the Deloro Mine Site. These were termed "exposed" sites. "Reference" locations were used to provide data for comparison from similar sites not affected by mining. River reference locations included sites on the Moira River upstream of Deloro, the Black and Skootamatta Rivers that are tributaries of the Moira River below Moira Lake, and the Salmon River located outside the watershed. Lake reference sites comprise Round Lake and Consecon Lake that are located outside the Moira River watershed.

Sediment Samples

Sediment sampling was conducted to examine metal concentrations with increasing depth of sediment and with distance downstream from the Deloro Mine Site. Metal concentrations in river and lake bottom sediment were determined from the analysis of 66 "grab samples" collected from exposed and reference sites (Figure 6). A further 11 sediment "core samples" were collected by taking sediment samples to depths of 30 cm at selected exposed sites. Selected grab samples were used for sediment toxicity testing in a laboratory. These tests included survival and growth tests using the freshwater shrimp, *Hyalella azteca,* and the midge, *Chironomus riparius.*

Figure 6 - Sediment Sample Collected at Stoco Lake

STUDY OVERVIEW AND FINDINGS

Benthic Invertebrate and Fish Samples

Bottom-dwelling (benthic) invertebrates and two fish species chosen to be representative of fish in close contact with sediments, were also evaluated for the presence of metals from the Deloro Mine Site. The fish species that were identified as "sentinel species", were white sucker and a small "minnow" called longnose dace. Contact with sediments was important as the metals from the Deloro Mine Site tend to accumulate in river and lake bottom sediments.

Benthic invertebrates were sampled at a total of 17 lake sites (including 11 exposed sites) and 18 river sites (including 11 exposed sites). The invertebrate communities at exposed and reference sites were examined for differences in the abundance (or number) of invertebrates found at a given location, as well as the overall species composition, and the presence or absence of sensitive species. Different physical habitat features (such as depth and texture of the sediment) were taken into account in this analysis.

Sampling was conducted for white sucker (Figure 7) at Moira and Stoco Lakes (exposed sites), and at Round and Consecon Lakes (reference sites). Few white sucker were caught in Stoco Lake and so white sucker were also collected from the Moira River at Bend Bay.

Figure 7 - White Sucker Specimen

Longnose dace were collected from two reference sites in the Moira River upstream of the Deloro Mine Site and from an exposed site immediately downstream of the mine. Fish from the reference and exposed sites were examined for differences in measures of fish health such as the size and age of each fish, relative sizes of internal organs, reproductive maturity and the incidence/presence of lesions and parasites.

STUDY OVERVIEW AND FINDINGS

Aquatic Effects Study - Findings

Water

There has been a significant improvement in water quality over the last 35 years, as illustrated in Figure 8. For example, arsenic concentrations in the Moira River at Highway 7 significantly declined in the early 1980s. These reductions reflect the cessation of processing activities and the effects of source control measures implemented by the ministry at the Deloro Mine Site. Since the 1980s, the concentrations of arsenic appear to fluctuate with changes in river flow. Drier years may be correlated with an increase in arsenic concentrations because mean annual flows are reduced. This is illustrated by the data from 1995 to 1999, which was a drier period. Mean annual arsenic concentrations have remained below the PWQO since the early 1980's, even during dry years.

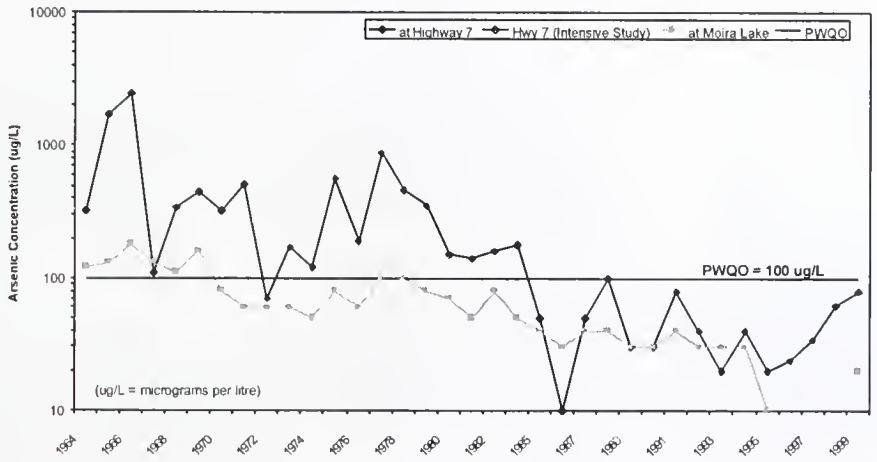

Figure 8 – Mean Annual Moira River Arsenic Concentrations

The concentration of metals of concern also declines steadily with distance downstream of the Deloro Mine Site. Since 1988, mean annual arsenic concentrations have not exceeded the PWQO of 100 micrograms per litre at downstream stations. The PWQOs were developed by the Ministry of the Environment to be protective of aquatic life, but as such, are not direct measurements of aquatic ecosystem health. Where water quality does not meet guideline values, all practical measures are to be taken to improve water quality.

STUDY OVERVIEW AND FINDINGS

Aquatic Effects Study - Findings

Sediments

Elevated metals concentrations are present in river bottom sediments at and downstream of the Deloro Mine Site. The highest concentrations of all the metals of concern are found in sediment collected from Young's Creek downstream from Highway 7. These sediments are currently contained by a series of beaver dams. This sediment could enter the Moira River if these dams were to fail.

The concentrations of metals in sediments within the Moira River gradually decline with increasing distance from the confluence with Young's Creek. The most substantial drop occurs after the outlet from Moira Lake. Concentrations of most metals of concern remain elevated above reference values, all the way to the farthest downstream station at Corbyville near Belleville.

Elevated concentrations of metals are present in the core sediment samples to the maximum 30 cm depth cored. This indicates that at least at these locations, more than 30 cm of sediment has accumulated since activities at the Deloro Mine Site began. At some of these locations, the highest concentrations were observed below a depth of 5 centimetres, suggesting the recent deposition of less contaminated sediments.

Provincial Sediment Quality Guidelines (PSQGs)

A set of guideline concentrations in sediment, expressed as lowest and severe effects levels (LELs and SELs) developed for the protection of aquatic life. These concentrations, or effects levels, are not direct measures of the health of an aquatic system. Exceedances of LELs or SELs typically indicate the need to conduct biological testing of aquatic organisms.

The sediment quality database for the metals of concern was examined for values that exceeded the Provincial Sediment Quality Guidelines (PSQG). PSQG values have not been developed for three of the metals of concern; specifically cobalt, silver and uranium. Sufficient data were available to develop site specific screening level concentrations (SLC) for cobalt and silver using methods detailed by the MOE. There were insufficient data to calculate an SLC for uranium; therefore uranium concentrations in the Moira River downstream of the Deloro Mine Site were compared to concentrations measured at the reference locations (upstream of the Deloro Mine Site and in other lakes and rivers in the area).

The concentrations in sediment of arsenic, copper, lead and nickel exceed the Severe Effect Levels (SELs) of the Provincial Sediment Quality Guidelines (PSQGs) at sampling stations from Highway 7 through to Moira Lake. Arsenic concentrations in sediment remain above the SEL in Stoco Lake and beyond (Figure 9). The results for lead appear to be strongly influenced by local geologic conditions and do not reflect a source at the Deloro Mine Site. Silver and cobalt concentrations exceeded site-specific screening level concentrations between Highway 7 and into Moira Lake. The only significant exceedances above reference concentrations for uranium were in Young's Creek sediments. Uranium concentrations were slightly above reference concentrations in portions of Moira Lake, Stoco

Lake and in the Moira River near Roslin. Although chemical measurements of uranium showed that it was elevated at certain locations, the radioactive

emissions from the amount of uranium present were always extremely low (even in Young's Creek). The radioactivity levels measured were significantly below any levels that have been shown to cause effects in aquatic plant and animal life.

Concentrations of metals in sediment that exceed Provincial Sediment Quality Guidelines (PSQG) identify the need to consider the potential for effects on the aquatic environment, particularly the benthic invertebrate community. Consistent with this guideline, an assessment of the benthic invertebrate community and selected fish species was included in the study design developed specifically for this *Study*.

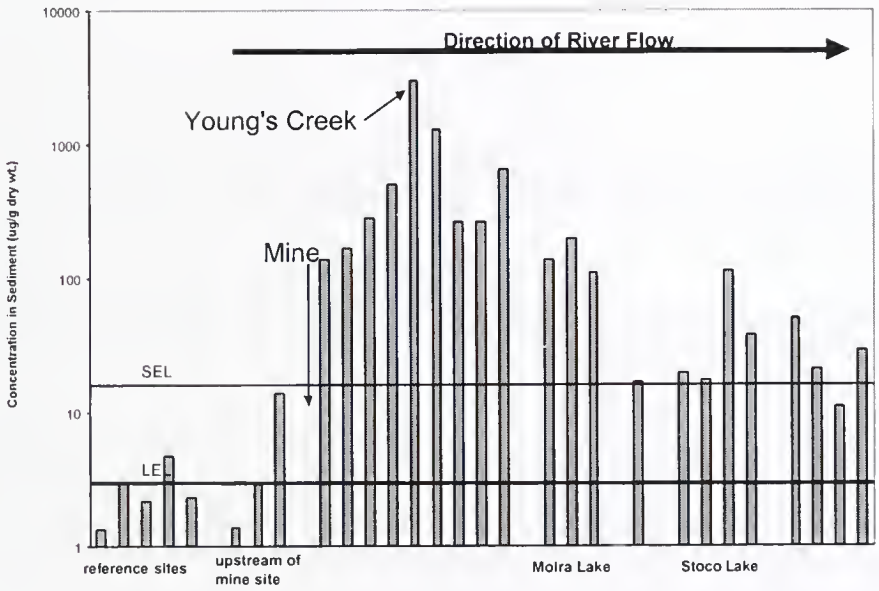

Figure 9 – Total Arsenic in Bottom Sediment – Moira River

Aquatic Effects Study - Findings

Benthic Invertebrates

The sediment analyses at benthic invertebrate sampling sites confirmed that benthic invertebrates are exposed to elevated metal concentrations.

Overall, the results of the benthic invertebrate study suggest a weak relationship between metals and the presence of some sensitive species in Moira and Stoco Lakes. No obvious adverse effects were observed in the benthic invertebrate community. Total abundance was not affected by elevated metal concentrations in the exposed lakes and Moira River sites. Fewer species were identified in Moira Lake although the pattern of species present did not correspond with elevated metal concentrations. Both abundance and percentage of metal-sensitive invertebrates were significantly reduced relative to reference lakes.

STUDY OVERVIEW AND FINDINGS

Moira Lake, Stoco Lake and Moira River sediments were not toxic to freshwater shrimp or midge larvae in the laboratory toxicity tests.

The abundance and diversity of benthic invertebrates in Young's Creek was reduced. Young's Creek sediments were toxic to freshwater shrimp and midge larvae in laboratory tests.

Aquatic Effects Study - Findings

Fish

Metal concentrations in whole-body white sucker samples, particularly at Bend Bay and Moira Lake, were significantly higher than the concentrations observed in samples collected at reference locations in the Moira River system. There were no differences in metal concentrations between smaller white sucker (< 30 cm length) and larger white sucker (> 30 cm length).

Arsenic, silver and nickel were the only metals present at significantly higher concentrations in longnose dace downstream of the Deloro Mine Site compared to the two upstream sites. Arsenic was the most elevated relative to the reference site data.

All but one of the fish health characteristics examined (mean age) in white sucker from Moira Lake were within the range of the characteristics observed in the two reference lakes (Round Lake and Consecon Lake). Thus there were almost no discernible effects on white suckers from elevated metals in Moira Lake. Similarly, no differences were noted for longnose dace despite their exposure to elevated concentrations of metals.

The results of the sentinel fish studies suggest that elevated metals concentrations have not caused an adverse effect in the fish species examined. It is possible that metals concentrations are not high enough to cause individual or population level changes in fishes or alternatively, these species have adapted over time to the environmental conditions in the Moira River system.

STUDY OVERVIEW AND FINDINGS

Objective #2:

Determine if and how the metals of concern pose any potential health implications to people living downstream of the Deloro Mine Site

Preliminary Quantitative Risk Assessment

A Preliminary Quantitative Risk Assessment (PQRA) was conducted to address objective #2.

The PQRA is a screening level assessment used to identify if and how users of the Moira River system may be exposed to metals of concern from the Deloro Mine Site. Given the conservative (i.e., health protective) nature of this assessment, this PQRA can identify and eliminate metals and exposure pathways not requiring further assessment. It can also identify which exposure pathways may represent a health concern to users of the river system, but it can not determine whether health impacts due to metals in the river system are actually occurring.

Methods

GlobalTox International Consultants carried out the Moira River Study PQRA, using methods that were consistent with the human health risk assessment conducted in the Village of Deloro in 1998-99.

The PQRA considers how users of the river system may come into contact with metals present in water, sediments and fish and then compares estimated exposures to benchmark values that represent acceptable or safe exposure. The exposure estimates are calculated using various conservative assumptions about the frequency of use of the river and/or lakes, activity patterns, characteristics of an individual and concentrations of metals. Because conservative assumptions are used, the exposure estimates are very likely to be significantly higher than any actual exposure. This is done to add layers of safety to the assessment. The benchmark values (toxicological reference values) have been developed by international agencies, such as the United States Environmental Protection Agency, to be protective of the most sensitive individuals and to represent acceptable health risks.

Given the highly conservative approach used, the results of this PQRA can be used to confirm the likely absence of risk in a given area, and eliminate that concern. This also helps to focus attention on metals and pathways of exposure that require further and more detailed study.

The PQRA evaluated the following pathways of exposure:

- Consumption of river or lake water for drinking water or cooking;
- Accidental swallowing of water during recreational activities such as swimming;
- Skin contact with water during recreational activities such as swimming;
- Accidental swallowing of sediment during recreational activities;

- Skin contact with sediment during recreational activities; and
- Eating of fish from the Moira River system.

Four areas of the Moira River system were assessed: Moira River from the Deloro Mine Site to Moira Lake (Study Area A); Moira Lake (Study Area B); Stoco Lake (Study Area C); and Moira River downstream of Stoco Lake (Study Area D) as shown in Figure 10. These areas were selected to reflect relative recreational use and metals concentrations in water and sediment. For example, Study Area A represents higher metals concentrations in water and sediment but lower recreational use. In contrast, Study Area B represents lower metals concentrations in water and sediment and higher recreational use.

Figure 10 - Preliminary Quantitative Risk Assessment (PQRA) Study Areas

To support this PQRA, a questionnaire regarding water usage was mailed out by the Ministry or hand delivered by the Moira Lake Property Owners Association to residents and cottagers in the area as far downstream as the outlet of Stoco Lake. The results returned by mail indicated that some people may be using the Moira River system as a source of drinking water. Consumption of water was therefore considered as a pathway of exposure.

Children aged 5 to 11 years were chosen as the most appropriate age group for assessment. This age group spends more time outside swimming and playing along the river's edge than either adults or younger children, and they are expected to have higher levels of exposure because of their activity patterns and physical characteristics. Exposure of children aged 5 to 11 years was estimated using physical characteristics and activity patterns for this age group, along with the results of water, sediment and fish fillet analyses for the metals of concern as developed elsewhere in this *Study*.

STUDY OVERVIEW AND FINDINGS

For the metals of concern in water, the yearly average and the ten-year average of yearly maximum concentrations were both considered. Sediment concentrations representative of swimming and wading areas that could be accessed by children were averaged from samples collected in a water depth of 1 metre or less. Average concentrations of metals, as observed in fish fillets from the 1999 MOE sport fish sampling program, were used.

The calculated exposure estimates were compared to benchmark values that represent levels of exposure that are considered acceptable. Exposure estimates greater than benchmark values may present a potential risk to human health.

For arsenic, the exposure estimates were also compared to the levels of exposure for a Typical Ontario Resident (TOR) to determine whether residents living downstream of the Deloro Mine Site may potentially be exposed to greater levels of arsenic than individuals living in other areas of the province. The Typical Ontario Resident's exposure represents the exposure to arsenic that individuals living in Ontario would receive from soil, water, air and food. Exposures calculated for the 5-11 year old child in the Moira River system that exceeded the TOR would indicate a potential concern under the conservative conditions assumed in this assessment.

Preliminary Quantitative Risk Assessment - Findings

Cadmium, chromium, cobalt, lead and nickel do not represent a potential health risk in any areas of the watershed and further assessment of the potential health risks posed by these metals is not required.

Exposure to arsenic in Study Areas C and D (Stoco Lake and the Moira River downstream of Stoco Lake) is not expected to be greater than that experienced by the Typical Ontario Resident (TOR). Further assessment of the potential health risks posed by arsenic in these areas is not warranted.

Residents of Study Areas A and B (from the Deloro Mine Site to the outlet of Moira Lake) have greater estimated levels of exposure to arsenic than the TOR under the conservative conditions assumed in the assessment, if river or lake water is used for drinking. Where water is not used for drinking, arsenic is not a concern for Moira Lake residents (Study Area B).

The section of the river above Moira Lake (Study Area A) is not well suited for in-water recreational activity and has only a limited number of residences. However, recreational use of this section of the river system may also be an important pathway for exposure to arsenic, at least for some individuals. The amount of exposure to arsenic through this pathway requires further study.

STUDY OVERVIEW AND FINDINGS

The concentrations of metals of concern found in fish fillets from the Moira River system are consistent with those observed elsewhere in Ontario and below that which could require restrictions of fish consumption. No further assessment of this pathway (i.e. eating of fish) is required. It should be noted that there is a fish consumption advisory for mercury in the Moira River system as well as in numerous other watersheds in Southern Ontario including the reference lakes sampled for this *Study*, Round and Consecon Lakes. The Deloro Mine Site is not a source of elevated mercury concentrations as determined from examination of the 35-year record of water quality results.

Predictive Modelling of Water and Sediment Quality

A water and sediment quality computer model was set up to address objective #3.

Objective #3:

Predict how the aquatic environment will improve in response to the final cleanup of the former Deloro Mine Site.

This model was constructed to assess the level of final cleanup that would be required at the Deloro Mine Site in order that arsenic, cobalt and nickel concentrations in the Moira River system would meet Provincial Water Quality Objectives (PWQOs). For the purpose of this model, the interim PWQO for arsenic of 5 micrograms per litre was used because the MOE has stated that one of the objectives of the final cleanup plan for the Deloro Mine Site is to meet this interim PWQO.

This model was developed as a decision tool to assist in the ongoing development of the final cleanup plan for the Deloro Mine Site. This model was not developed for the detailed simulation of processes such as storm events but rather, was based on long-term average conditions. Predictions are meant to serve as general indicators of the response of the Moira River system to future cleanup actions at the Deloro Mine Site.

Methods

The computer model was constructed to simulate long-term water and sediment quality in the Moira River system between the Deloro Mine Site and the outlet of Stoco Lake. Arsenic, cobalt and nickel were selected for modelling as being representative of the behaviour and concentrations of the metals of concern. The Moira River above Deloro already contains a certain amount of arsenic, cobalt and nickel. These background concentrations in water were incorporated into the model. The amounts of arsenic, cobalt and nickel from the Deloro Mine Site were determined from existing studies and by examining the difference in metals concentrations and river flows between upstream and downstream sampling stations. Much of the arsenic, cobalt and nickel added to the river system originates from the Deloro Mine Site, the result of years of mining and refining activities. The water quality data suggest that some loadings, particularly for cobalt, may also originate in the section of the river between the Deloro Mine Site and just below the confluence with Young's Creek. The loading of metals from Young's Creek was relatively minor because of the low flow in this tributary. All the calculated quantities, or loadings, of arsenic, cobalt and nickel were

STUDY OVERVIEW AND FINDINGS

incorporated into the model.

The model incorporated the main processes that control the movement and concentrations of metals in water and sediment (e.g., the tendency to remain dissolved rather than being attached to sediments, sediment settling and re-suspension of metals from the sediment).

The process of sediment transport down a river system occurs on an ongoing basis and is influenced principally by the size of sediment particles and the flow of water. Typically, sediments are deposited in areas of quiet, slow moving water and are picked up and transported further downstream when flows increase. Much sediment transport occurs during spring runoff and major storm events. Wind and ice scour can also affect sediment deposition in shallow portions of a river where they are readily picked up (i.e., re-suspended) and transported further downstream. Deep lakes, on the other hand, act as basins where sediments accumulate. Thus, metals originating from the Deloro Mine Site that bind to sediment have accumulated primarily in the deeper basins of Moira Lake.

Water quality in the Moira River is affected by the quality of the contributing streams and water originating from the Deloro Mine Site as noted above. In addition, metals that are present in sediment can over time, 'dissolve' back into the overlying water, thereby affecting water quality. Thus over time, the sediments in the Moira River system provide a continuing source of metals to the overlying water, a process that was considered in the model.

The model was based on average, long-term monthly river flows. The river was divided into nine segments, each characterized by similar flow patterns and processes (see Figure 11). The model was used to predict water and sediment quality in each of these segments.

The Moira River Model was calibrated (i.e., checked for its ability to correctly reproduce measured metal concentrations) using historical water flow and water quality data, results from the 1999 sediment sampling, and by adapting input values (e.g. settling velocity and chemical partitioning rates). The model was calibrated to reflect general long-term water quality trends observed over the last 10 years. Data detailing the changes in sediment quality over time have not been developed and, as such, the model was calibrated against sediment quality results developed during this *Study* only.

STUDY OVERVIEW AND FINDINGS

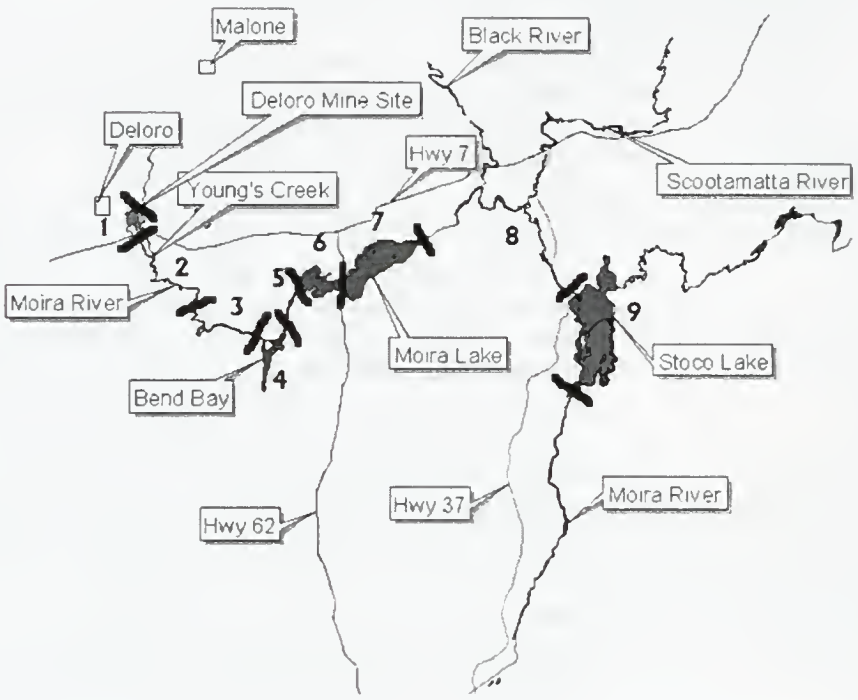

Figure 11 - River Segments for Water and Sediment Quality Model

Predictive Modelling of Water and Sediment Quality– Findings

The model showed that water quality would continue to improve over time. However, the improvement relative to Provincial Water Quality Objectives varies with each metal considered.

If arsenic migration from the Deloro Mine Site is essentially eliminated (99% reduction), the model results indicated that arsenic concentrations in the Moira River at Highway 7 would meet the interim PWQO during periods of high flow only. During periods of low flow, the interim PWQO for arsenic would still be exceeded even after 30 years. This is because a relatively small amount of arsenic from the site, coupled with the relatively high background concentrations in the Moira River upstream of the mine, would still be significant relative to the interim PWQO of 5 micrograms per litre. The interim PWQO would be met in Moira Lake and further downstream after 99% reduction of arsenic leaving the Deloro Mine Site. The model accounted for continual release of arsenic from sediments in the bottom of Moira Lake back into the lake water. Although the release from sediment was predicted to have a slight effect on arsenic concentrations in lake water, this would not be sufficient to cause exceedances of the interim PWQO in Moira Lake.

The results of the model show that cobalt will continue to exceed the PWQO as

far downstream as the outlet of Moira Lake, even with the essentially complete elimination of cobalt loadings from Deloro Mine Site. Below Moira Lake, cobalt concentrations would meet the PWQO within 5 years because of the effects of dilution from the Black and Skootamatta Rivers.

The nickel PWQO is currently being met in the Moira River on an annual average basis; however exceedances occur in the section between the mine site and Bend Bay, only in periods of low flow. The PWQO would be met year-round after reduction or elimination of nickel from the Deloro Mine Site.

Sediment quality will improve slowly over the long term independent of final cleanup actions at the Deloro Mine Site. Even if the migration of metals from the Deloro Mine Site is essentially eliminated, sediment quality is unlikely to meet Provincial Sediment Quality Guidelines in the river system down to and including Stoco Lake for a period of more than 30 years because of the very slow rate at which new clean sediment will accumulate.

CONCLUSIONS

The overall goal of the study was to assess the extent and significance of metals concentrations and predict the environmental response to cleanup activities that will in the future be conducted at the Deloro Mine Site. The main conclusions of the study are outlined below.

1. The study confirmed the presence of elevated levels of arsenic, cobalt, copper, lead, nickel and silver in sediments and water of the Moira River system. Uranium is elevated in sediments in Young's Creek; however, the radioactivity from the amount of uranium present can not be distinguished from reference levels. Other radionuclides are not a concern at any location in the Moira River system.

2. Water quality has improved significantly over the past 35 years, in response to the cessation of processing activities and the ministry's cleanup activities at the mine site. Since the mid 1980s, arsenic, copper and nickel exceed the PWQO only at times of low river flow in the section of the river between the Deloro Mine Site and Bend Bay. For cobalt and lead, the PWQO is exceeded during low flow between the Deloro Mine Site and the outlet of Moira Lake.

3. Elevated concentrations of metals are present in sediments extending from below the Deloro Mine Site to downstream of Stoco Lake. The highest concentrations of metals are found in sediments in Young's Creek and in the deep basins of Bend Bay, Moira Lake and Stoco Lake.

4. Provincial Sediment Quality Guidelines (PSQG) are exceeded in the river system and for arsenic and nickel, these exceedances extend from the Deloro Mine Site through Moira and Stoco Lakes and further downstream.

5. Despite the exceedances of PWQOs during low flow and exceedances of PSQGs, no obvious adverse effects were observed in benthic invertebrates and fish populations in the Moira River, Moira Lake or Stoco Lake. Effects were observed on invertebrate abundance and species diversity in Young's Creek.

6. Cadmium, chromium, cobalt, lead and nickel do not represent a potential health risk to residents of the Moira River watershed and further assessment of the potential health risks posed by these metals is not required.

7. Exposure to arsenic in the Moira River downstream of Moira Lake is not expected to be greater than that of the Typical Ontario Resident (TOR), and further assessment of the potential health risks posed by this substance in these downstream areas is not warranted.

CONCLUSIONS

8. The reminder issued by the MOE and the Hastings and Prince Edward Counties Health Unit to residents of Study Areas A and B (from the Deloro Mine Site to the outlet of Moira Lake) advising them not to drink untreated surface water was, and continues to be, appropriate. The reminder is not only appropriate because of concerns about arsenic, but also because of the risk of exposure to pathogens in untreated water. If residents drink untreated water from the river or lake, they would have greater estimated levels of exposure to arsenic than the TOR under the conservative conditions assumed in this assessment. Where water is not used for drinking, arsenic is not a concern for residents and cottagers on Moira Lake.

9. Exposure to sediments in Study Area A during recreational use (wading or swimming) was identified as a potentially important exposure pathway. Further study was recommended. [This further study has since been conducted. The results show that exposure to the range of concentrations of arsenic detected in sediment in Study Area A will not result in adverse health effects after short-term or long-term exposure of area residents and other users of the river. Therefore, no specific risk management measures are required with respect to exposure to sediments in Study Area A.]

10. The concentrations of the metals of concern in fish fillets are below the levels that would require restrictions of fish consumption. However a fish consumption restriction for Moira and Stoco Lakes is in effect because of mercury; a substance not related to the Deloro Mine Site. Consumption restrictions based on mercury are widespread throughout Ontario's lakes and rivers, including the reference lakes considered for this *Study*.

11. The water quality data suggests that there may be an additional, so far undefined source of some cobalt to the Moira River, somewhere between the Deloro Mine Site and immediately below the confluence with Young's Creek.

12. The results of the predictive modelling indicated that the loading of arsenic and cobalt to the Moira River from the Deloro Mine Site would have to be essentially eliminated for downstream water quality to meet PWQOs. For arsenic, the interim PWQO of 5 micrograms per litre would not be met at Highway 7 during low flows even after 99% reduction; however it would be met year-round in Moira Lake and further downstream. The PWQO for cobalt would only be met below Moira Lake. Mean annual concentrations of nickel currently meet the PWQO; after cleanup, the PWQO would be met year round.

CONCLUSIONS

13. Sediment quality downstream from the Deloro Mine Site in the Moira River will continue to improve over the long term. However metals concentrations in sediment in the Moira River system down to and including Stoco Lake will remain above PSQGs for many years to come, independent of cleanup actions at the Deloro Mine Site.

14. The amount of metals reaching the Moira River from Young's Creek is relatively small compared to the amount from the Deloro Mine Site. However, the presence of a significant quantity of sediments retained behind a series of beaver dams is a concern. Should these dams fail, a significant quantity of sediments could be released to the Moira River.

RECOMMENDATIONS

1. The drinking water reminder to residents and cottagers in the Moira River watershed extending from the Deloro Mine Site to the outlet of Moira Lake not to use the river system as a source of drinking water should be continued.

2. The current monitoring programs for water quality and river flows conducted on behalf of or by the MOE should be continued.

3. Further assessment of the possible exposure of residents to arsenic in sediments during recreational activities, in Study Area A (Deloro Mine Site to the inlet of Moira Lake) is recommended. This assessment, an Updated PQRA, has since been conducted, the results of which have shown that further assessment of the potential health risks associated with arsenic in sediments in Study Area A is not warranted. The assessment which was conducted reflects the conditions at the time of sediment sampling. Should conditions change due to a major flood event, or in the event of a significant accidental release of sediments from Young's Creek, follow up sediment sampling would be recommended to confirm that exposure to sediments in Study Area "A" continues to represent no significant incremental health risk. Following completion of the final cleanup program for the Deloro Mine site, including Young's Creek, would also be an appropriate time for follow up sediment sampling.

4. An assessment of a possible source or sources of metals along the section of the Moira River between the Deloro Mine Site and immediately below the confluence with Young's Creek should be conducted. This assessment should include a review of mass loadings using the most recent water quality data.

5. As a precautionary measure, the public should be advised to avoid recreational activities in Young's Creek south of Highway 7 until such time as further characterization of sediment and water quality in this area has been completed. This characterization should also include an assessment of baseline biological conditions in Young's Creek including both aquatic and terrestrial resource components.

6. Subject to the results developed from the above recommendation, options to eliminate the likelihood of a release of sediments to the Moira River from Young's Creek should be evaluated and incorporated into the final cleanup plan for the Deloro Mine Site.

7. Development of the final cleanup plan for the Deloro Mine Site does not need to include consideration of effects in the downstream aquatic environment because benthic invertebrates and fish populations do not show adverse effects from the presence of metals in the Moira River system.

8. Development of the final cleanup plan for the Deloro Mine Site should include consideration of downstream water quality to reduce potential human health concerns associated with the presence of arsenic.